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STIMULUS-DRIVEN CAPTURE AND ATTENTIONAL SET: SELECTIVE SEARCH FOR COLOR AND VISUAL ABRUPT ONSETS

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SUMMARY

Recent evidence suggests that the occurrence of attentional capture is contingent on the attentional control setting induced by the task demands (Folk, Remington & Johnston, in press). Because the experiments on which these conclusions are based can be criticized for several reasons, the contingent capture hypothesis was tested by means of two visual search tasks in which subjects searched multi-element displays in which a color singleton and onset singleton were simultaneously present. When subjects had to search for a color singleton, on some trials another location contained an irrelevant onset. In addition, when subjects had to search for a onset singleton, on some trials another location contained an irrelevant color singleton. Both experiments show that the contingent capture hypothesis does not hold: irrespective of attentional set, attention was captured by the most salient singleton. The results of these experiments, together with previous findings, suggest a stimulus-driven model of performance in which selection is completely determined by the properties of the objects present in the visual field.

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Selectief zoeken naar kleur en luminantieveranderingen

J. Theeuwes

SAMENVATTING

In een recente studie (Folk, Remington & Johnston, in druk) werd aangetoond dat de mate waarin een object de aandacht trekt, afhankelijk is van de taakinstructies. Omdat er een aantal problemen zijn met de studie van Folk et al., werd deze hypothese getest door middel van twee visuele zoektaken waarbij proefpersonen dienden te zoeken naar een object met een unieke kleur of naar een object met een "abrupt onset". Beide experimenten laten zien dat de hypothese van Folk et al. verworpen dient te worden: ongeacht de taakinstructies wordt de aandacht getrokken door het object met de hoogste opvallendheid.

1 INTRODUCTION

Among the most fundamental issues of visual attention research is the extent to which visual selection is controlled by the properties of the stimulus or by the intentions, goals and beliefs of the observer (see e.g., Yantis, in press). It is generally assumed that visual selective attention can be controlled in either a goal-directed or a stimulus-driven manner. Selection is thought to occur in a goal-directed, voluntary manner when the observer intentionally selects only those objects required to perform the task at hand. Selection is thought to occur in a stimulus-driven, involuntary manner when selection is determined by the specific properties of the objects present in the visual field, irrespective of the intentions or goals of the observer.

In order for visual *selection* to be involved, it is required that different sources of information are simultaneously present in the visual field. Selective attention controls which objects embedded in an array of other objects are selected for further processing. Before selective attention operates, preattentive processes perform some basic analyses segmenting the visual field into functional perceptual units. If spatial attention is directed towards such a perceptual unit, this unit is thought to be selected (e.g., Broadbent, 1958, 1982). It is commonly assumed that this preattentive segmentation is limited to a set of primitive features or properties of objects such as color, shape, size and brightness (e.g., Treisman & Gelade, 1980). Since visual search for these properties is independent of the number of elements in the display, the preattentive segmentation process is thought to operate without capacity limitations and in parallel across the visual field (e.g., Broadbent, 1958; Neisser, 1967). The preattentive segmentation process provides the perceptual units, and crucial question is whether the subsequent allocation of attention to these perceptual units is under the control of the strategic plans of the observer or under the control of stimulation (e.g., Neumann, 1984).

In the absence of a clear strategic plan, Jonides & Yantis (1988) and Theeuwes (1990) showed that, in a visual search task, the mere presence of a featural singleton in color, brightness or shape, was not enough to capture attention involuntary. When searching for a target which could not be detected preattentively (e.g., Jonides & Yantis, 1988: searching for a target letter between other letters), the irrelevant featural singleton was simply ignored and the time to find the target linearly increased with the number of elements in the display. On the other hand, even in the absence of a clear strategic plan, abrupt changes in luminance over time—abrupt onsets (Jonides, 1981; Jonides & Yantis, 1988; Müller & Rabbitt, 1989; Posner, 1980, Yantis & Jonides, 1984) and offsets (Miller, 1989; Theeuwes, 1991a)—can generate involuntary shifts of attention. Jonides & Yantis (1988), for example, showed that in a visual search task, a letter with abrupt onset was always selected first even when there was no benefit to the observer to intentionally allocate attention to the onsetting item.

Recently, however, Yantis & Jonides (1990) and Theeuwes (1991a) showed that when search is eliminated by cuing with absolute certainty the spatial location of the impending target, abrupt onsets and offsets elsewhere in the visual field do *not* capture attention. Such result was predicted because, in anticipation of the target event, spatial attention was already directed to the location of the impending target, suggesting that *visual selection*—controlling which object embedded in an array of other objects is selected for further processing—took place *before* the search display came on. Because the cuing procedure eliminates spatial uncertainty, it is not required to select a target object among other objects, with the consequence that the preattentive parallel segmentation stage which normally precedes the selection stage does not occur.

Theeuwes (1991b, 1992) showed that in visual search tasks in which observers have a clear strategic plan to selectively attend to only the task-relevant stimulus property, irrelevant featural singletons in a different dimension as the relevant one, disrupted performance (see also Pashler, 1988, Experiment 6). For example, in Theeuwes (1992), observers had an attentional set for a shape singleton because they searched for a green circle among green squares. When on some trials, an irrelevant color singleton was present (i.e., one of the green squares was red) search performance was disrupted. Even though observers had a clear attentional set to attend to a shape singleton, the irrelevant color singleton captured attention involuntary. Theeuwes (1991b, 1992) showed that selectivity depended solely on the relative saliency of the stimulus attributes: when the shape singleton was more discriminable than the color singleton, the shape singleton interfered with search for the color singleton, and vice versa. It was concluded that in visual search tasks in which a preattentive segmentation process is required to detect the target, the attentional set cannot not override the stimulus-driven capture that arises due to the appearance of a more salient stimulus attribute. Theeuwes (1991b, 1992) claimed that in visual tasks selection occurs in purely stimulus-driven fashion.

In a recent article, Folk, Remington and Johnston (in press) challenged this claim and suggested that the control of attention is *never* purely stimulus driven. They claim that the stimulus-driven control exerted by the objects present in the visual field depends on the observer's state of attentional readiness. Under conditions of spatial uncertainty, they show that an onset singleton, referred to as a "dynamic discontinuity", does not capture attention when observers adopt an attentional set for static singletons, referred to as a static discontinuity (e.g., look for an item with a unique color). On the other hand, when observers are set to identify a static singleton, they cannot ignore another irrelevant static singleton. Folk et al. conclude that all attentional shifts are mediated by "programmable" control settings. The conclusions of Folk et al. are important as, for example, acknowledged by Yantis (in press): "the central point made by Folk et al. (in press)—that the bottom-up control of attention by stimuli interacts with the observer's state of attentional readiness—provides an important foundation for further developments in attentional theory" (p. 4 of ms).

In spite of the significance of Folk et al.'s (in press) findings their results should be considered with care. In their study, subjects responded to a letter shape (X vs. =) which, in different conditions, had either a unique color or a unique abrupt onset. When the search display was preceded by a to-be-ignored featural singleton (the "cue") that matched the singleton they were searching (e.g. searching for a unique color with a cue that contains a unique color as well), the cue captured attention as evidenced by a prolonged reaction time to identify the target. On the other hand, if the to-be-ignored featural singleton did not match the singleton they were searching (e.g., searching for unique color with the cue containing an unique onset) the onset did not capture attention. This "contingent" capturing of attention occurred for both color and onset, and is considered as evidence that involuntary capture is contingent on the adoption of some attentional set and will not occur if such a set is not adopted.

Although the account presented by Folk et al. (in press) appears to be sound, their conclusions could be delusive conceivably due to the usage of the word "cue". If one simply looks at the exact experimental procedure, the results can be predicted without the conjecture that involuntary capture depends on the attentional control settings. The cue and search display were presented in fast successive order (both displays within 200 ms) and it is likely that some integration over time took place. It will appear that both cue and search display are presented more or less at the same time, with the cue possibly being more salient because it is presented somewhat earlier in time. In conditions in which the cue is invalid (i.e., it signals the location where the target will not appear) and matches the target defining attribute, it appears that two colored (color condition) or two onsetting (onset condition) items are simultaneously present in the visual field. Attention is involuntary switched to the location of the more salient feature (i.e., the cue which is presented a little earlier) followed by an involuntary switch to the less salient feature (the target), giving relatively long reaction time to identify the target. If the cue signals the valid location and matches the target defining attribute, there appears to be only one uniquely colored (color condition) or one onsetting (onset condition) item present in the visual field and attention is involuntary switched to the only location that contains a unique feature. Reaction times to identify the target will be fast. If the cue signals an invalid location and does not match the target defining attribute, two items, one with a unique color and one with a unique onset are present in the visual field and the reaction time will be completely determined by the relative saliency of the cue and target feature. Reaction time will neither be fast nor slow. Finally, if the cue signals a valid location and does not match the target defining attribute, attention is switched to the only location having both a unique color and onset. Because two unique features are present at the same location, time to *identify* the target will be affected, giving reaction times which will be neither fast nor slow.

The above is a complete account of Folk et al.'s results without assuming any top-down control: attention is simply switched in the order of the saliency of the features present in the visual field. Yantis (in press) hinted towards this explanation when he suggested that the Folk et al.'s (in press) study reveals that attentional set cannot be switched over very small time scales (p. 10 of ms). There are other less severe problems with the Folk et al.'s (in press) study. For example, the task employed was not really a search task, because in the onset condition, the onsetting item was the only element present in the visual field (see also Yantis, in press, footnote 3). In addition, because there is no check on whether subjects divide their attention over the visual field, in the invalid cue condition, for example, subjects might have focussed their attention on a (random) location in visual field before display onset. As noted earlier, focussing of attention to a location reduces the distracting effect of events falling outside the attentional beam (Yantis & Jonides, 1990; Theeuwes, 1991a). Finally, Folk et al.'s (in press) conclusions are reached after multiple comparisons between the valid and invalid to-be-ignored "cue" condition with two control conditions in which there is a central cue or no cue. Such cost-benefit analyses are troublesome (e.g., Jonides & Mack, 1984), and seem particularly inappropriate for "cue" conditions in which the cue has to be *ignored*.

Because the conclusions of Folk et al. (in press) are important, it is essential to test their hypothesis with an uncomplicated task which does not allow alternative interpretations. In the present study, subjects had to selectively search for either a color (attentional set for color singleton) or an onset singleton (attentional set for onset) embedded between 3 or 6 nontarget items in the visual field. Variation of display size enabled to check on whether search was performed in parallel or serially. As indicated, if search is performed serial or partially serial, visual selection operates on one or a few items at a time, blocking out the possible capturing effect of visual information outside the "selected" area on which attention is focussed (e.g., Yantis & Jonides, 1990; Theeuwes, 1991a). When subjects had a attentional set for a color singleton, on some trials another location contained an irrelevant onset. In addition, when subjects had a attentional set for onset, on some trials another location contained an irrelevant color singleton. The task was designed such that subjects needed to attend to the location that was cued by singleton of the attentional set.

According to the Folk et al.'s (in press) hypothesis that involuntary capture of attention is dependent on the control settings, it is expected that an abrupt onset does not capture attention when subjects have an attentional set for a color singleton. Time to identify the target signalled by the color singleton should not be affected by the presence of an irrelevant onset. In addition, when subjects have a clear attentional set for onset, the presence of a irrelevant color singleton should not affect performance.

Alternatively, Theeuwes' (1991b, 1992) hypothesis that visual selection depends on the relative saliency of the singletons present in the visual field, predicts that, irrespective of attentional set, a singleton with high saliency disrupts search for a less salient singleton.

2 EXPERIMENT 1

2.1 Method

Subjects

Eight right-handed subjects, ranging in age from 18 to 23 years, participated as paid volunteers. All had normal or correct-to-normal vision and reported having no color vision defects.

Apparatus and stimuli

A SX-386 Personal Computer (G2) with a NEC Multisync 3D VGA color screen (resolution 640x350) using Micro Experimental Laboratory software package controlled the timing of the events, generated pictures and recorded reaction times. The "/"-key and the "z"-key of the computer keyboard were used as response buttons. Each subject was tested in a sound-attenuated, dimly-lit room, his or her head resting on a chinrest. The CRT was located at eye level, 115 cm from the chinrest.
The display elements consisted of green (CIE x,y chromaticity coordinates of .303/.594) or red (coordinates of .630/.353) outline circles which were matched for luminance (16.5 cd/m^2). The fixation cross and the line segments were presented in white (33.0 cd/m^2) on a black background (0.5 cd/m^2).

Procedure

The task was similar to that in Theeuwes (1991b, 1992), consisting of a visual search task in which there is a clear separation between the defining and reported attribute of the target. Subjects responded to the orientation (horizontal or vertical) of a line segment appearing inside a red circle embedded among green circles (color condition) or in a red outline circle with abrupt onset embedded among no-onset circles (onset condition). Because subjects responded to the orientation of a target line segment located among slightly tilted nontarget line segments, the task required focal attention (Theeuwes, 1991b; Treisman & Gormican, 1988) but not a high spatial acuity. The "no-onset" and "onset" stimuli were constructed analogously to Jonides and Yantis (1988), in which onset stimuli were presented in previously blank locations, and no-onset stimuli were camouflaged by premasks.

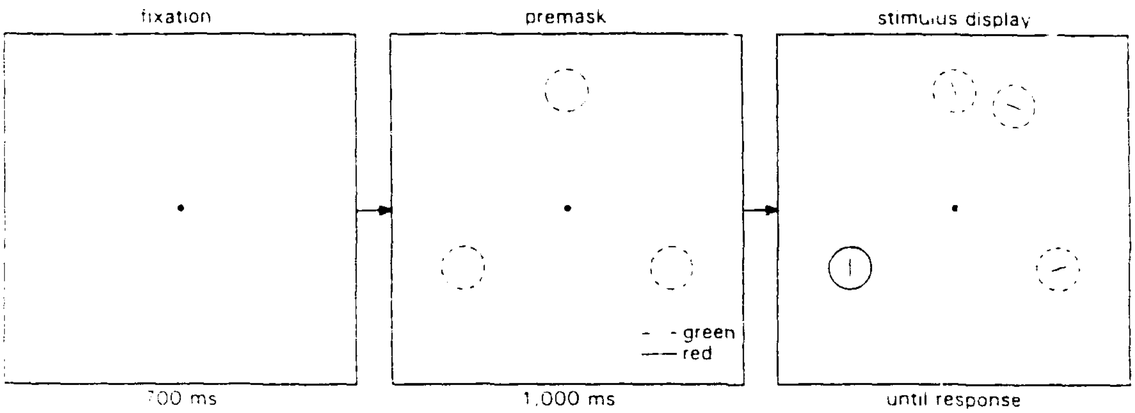

Fig. 1 Trial events in Experiment 1 (In this example, the color distractor condition in which subject have an attentional set for a color singleton; the target is vertical and located in the color singleton, the distractor is an irrelevant circle with abrupt onset.

The trial events are shown in Fig. 1. At the beginning of a trial a central dot appeared, upon which subjects remained fixated throughout a trial. After 700 ms, the "standard" premask was presented consisting of three or six green outline circles (1.2° of diameter) which were equally spaced around the fixation point on an imaginary circle whose radius was 3.4°. The six circles formed a hexagon; the three circles formed either a upward-pointing or down-pointing equilateral triangle. Each circle contained six line segments (0.5°), one vertical, one horizontal and four tilted 20° to either side of the horizontal and vertical plane. After 1,000 ms premask the stimulus field was presented. At the end of the 1,000-ms premask period, 5 of the 6 line segments in each of the circles were extinguished, revealing line segments that were tilted 20° to either side of the horizontal or vertical plane. The orientations were randomly distributed in a display. In only one circle, the extinguished line segments revealed a line segment oriented either horizontally or vertically; the orientation determined the appropriate response key (the "/"-key for vertical and the "z"-key for horizontal). In the color condition, at the end of the 1,000-ms premask period, one of the green circles changed into a equiluminant red circle, which contained the horizontal or vertical target line segment. In the onset condition, at the end of the 1,000-ms premask period, a green circle containing the target line segment was presented at one of the 6 previously blank locations of the 3.4° imaginary circle. The stimulus field remained present for a maximum of 2 s until a response was emitted.

In the color condition, subjects received two conditions: (1) a no-distractor condition in which the red circle containing the target line segment was surrounded by 3 or 6 green circles, and (2) a distractor condition in which one of the 3 or 6 green circles had abrupt onset. In the onset condition subjects received two conditions as well: (1) a no-distractor condition in the green circle with abrupt onset was surrounded by 3 or 6 green circles, and (2) a distractor condition in which one of these green circles was red. As will be clear, when searching for a uniquely colored red circle, the distracting element was a green circle with abrupt onset, and when searching for a green circle with abrupt onset the distracting element was a uniquely colored red circle. The position of the red target circle in the stimulus display was randomized from trial to trial, it replaced always one the circles from the premask display. The position of the onset circle was randomized as well, yet it was presented at one of the six blank locations. At the end of the premask period, in all except one condition, a circle with abrupt onset was added to the 3 or 6 circles of the premask display, creating a stimulus field consisting of 4 or 7 circles. In the no-distractor color condition however, no circle with abrupt onset was added at the end of the premask period. In order to keep an equal number of elements in the stimulus display, in this condition the premask consisted of the standard 3 or 6 circles with an additional circle at one of the locations that contained an abrupt onset circle in the other conditions.

Each subject performed both a color and a onset session. Both the color condition session and the onset condition session consisted of 96 practice trials (half of the trials no-distractor, the other half distractor) followed by a block of 144 trials in the no distractor condition and 144 trails in the distractor condition. Half of the subjects started with the color session, the other half with the onset session. Within the color and onset sessions, half of the subject started with the no-distractor the other half with the distractor condition. Display size (4,7) was randomized within blocks. Each subject performed a total of 576 trials- that is, a total of 72 trials in each display-size distractor condition.

Each session lasted approximately 40 minutes, with a 15 minute break between the sessions. Within a session, there were short breaks after 72 trials in which subject received feedback about their performance (percentage errors and mean reaction time) on the preceding block of trials. Prior to the start of the experiment subjects were instructed to search for the horizontal or vertical target line segment and to press the appropriate response key with one of their index fingers which were resting on "/" and "z"-keys. Before each session, the subjects were informed about the relationship between the location of the target line segment and the unique display element: in the color condition, subject were told that the target line segment was always located in the uniquely colored red circle; in the onset condition they were told that the target line segment was always located in the circle with abrupt onset. They were instructed to use this information. It was emphasized that subjects should fixate the central dot and not move their eyes during the course of any trial. It was stressed that a steady fixation would reduce RT and make the task easier. Both speed and accuracy were emphasized. A warning beep informed the subject that an error had been committed. If no response was made after 2 s, subjects were informed that they had committed an error.

2.2 Results

Response times longer than 1 s were counted as errors, which led to a loss of well under 1% of the trials. Fig. 2 presents the subjects' mean RT and error percentages in the four conditions. The individual mean RTs were submitted to an ANOVA with attentional set (search for color, search for onset), display size (4,7) and distractor as factors.

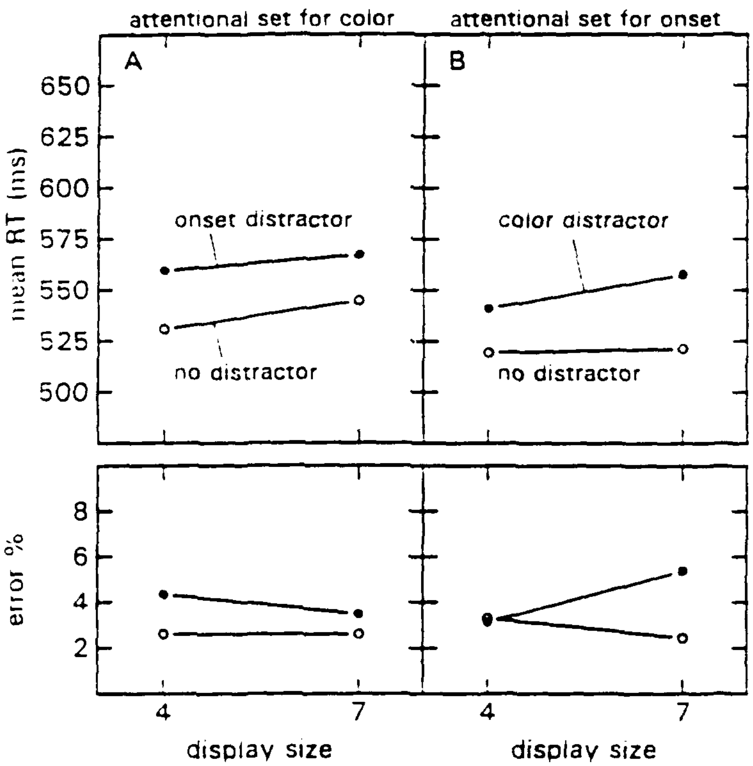

Fig. 2 Experiment 1: Mean reaction time and error percentages for search with or without a distractor for the color (Panel A) and onset (Panel B) conditions.

There was a main effect on RT for both display size and distractor [$F(1,7) = 6.3$; $p < 0.05$, for display size, and $F(1,7) = 29.2$; $p < 0.01$ for distractor]. The mean slopes for the color condition, were 4.7 and 2.6 ms for the no-distractor and distractor condition. For the onset condition, these figures were respectively 0.6 and 5.5 ms. None of these slopes were significantly different from zero (all $t(7) < 1.27$), indicating parallel preattentive search across all items in the display. Inspection of the RT data reveals that when subjects are searching for a uniquely colored red circle, they are distracted by the abrupt onset. In addition, when subjects are searching for a abrupt onset, they are distracted by the uniquely colored red circle.

An additional analysis showed that distraction effect on RT did not depend on the order of the presentation of the color and onset sessions. The interaction between presentation order and distractor was not significant [$F(1,6) < 1$] suggesting that the distraction effect is not due to some transfer from one condition to the next.

In order to achieve homogeneity of the error rate variance, the mean error rates per cell were transformed by means of an arcsine transformation. There was only a main effect for distractor [$F(1,7) = 11.7$; $p < 0.05$]. Because this analysis indicates that error differences are non-significant or tend to mimic RT, differences in response latencies are not due to a speed-accuracy trade-off.

2.3 **Discussion**

The results of this experiment are fairly clear: when subjects have an attentional set for a color singleton (a static discontinuity), an abrupt onset (a dynamic discontinuity) captures attention involuntary, as evidenced by a prolonged reaction time to identify the target line segment inside the color singleton. In addition, when subjects have an attentional set for an abrupt onset, also a color singleton captures attention involuntary. The results indicate that Folk et al.'s (in press) hypothesis that involuntary capture of attention is dependent on the control settings does not hold: even when subjects have a clear attentional set for a static discontinuity, a dynamic discontinuity interferes, and vice versa.

The results agree with Theeuwes' (1991b, 1992) hypothesis that visual selection depends on the relative saliency of the singletons present in the visual field. In conditions in which there is only one singleton present (i.e., the no-distractor condition) the mean RT represents the relative saliency of the singleton, that is, it depicts the time it takes for attention to be captured by the singleton. The RT analysis indicates, as evident in Fig. 2, that the mean RTs averaged over display size for the no distractor conditions color and onset were not different (550 ms for color and 535 for onset) suggesting that they did not differ in their saliency. In line with the hypothesis of Theeuwes, comparable interferences for the color and onset conditions were expected and observed.

The finding that for all search functions, RT did not increase with display size, indicates that search for the color singleton and abrupt onset was performed in parallel. The finding that search is not serial ensures that subjects did not focus their attention on some restricted area in the visual field. As indicated, focussing of attention to one or a few items will give serial search which might attenuate the distracting effect of the irrelevant item.

The present findings showing that an attentional set for a static discontinuity cannot override the stimulus-driven capture of the dynamic discontinuity and vice versa might contain a confound because at stimulus presentation two elements are changed. One element changed its green color into an equiluminant red color and one element was added. If subjects simply attend to "change" irrespective of whether this is a color change or a luminance change, then, due to an attentional set for "change", interferences can be expected.

Experiment 2 was designed to test this possibility. Rather than changing the color of a single circle, the color of all except the target circle was changed so that an attentional set for change per se was not an appropriate strategy. In addition, to test Theeuwes' hypothesis, the color difference was made smaller so that the onsetting element had a higher saliency than the color singleton. According to the Folk et al.'s (in press) hypothesis, it is expected that the time to identify the target signalled by the less salient color singleton is not affected by the irrelevant onsetting element. According to Theeuwes' (1991b, 1992) hypothesis, attention is automatically captured by the most salient element suggesting that the time to identify the target signalled less salient color singleton is prolonged. On the other hand, search for the abrupt onset with a relatively high saliency is not affected by the presence of the less salient color singleton.

3 EXPERIMENT 2

3.1 **Method**

Subjects

Eight subjects ranging in age between 20 and 25 years participated in the experiment.

Apparatus

The apparatus was identical to Experiment 1. The premask consisted of grey circles. Rather than changing the color of one circle as in Experiment 1, at the end of the premask period, the color of all circles expect one was changed into an equiluminant red[1] (CIE x,y chromaticity coordinates of .265/.278 for grey and .628/.352 for red; luminance of 17.3 cd/m^2).

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[1] The color grey was chosen for the premask because, due to the steady fixation, colors such as green, red or blue will induce a local chromatic adaptation (see Theeuwes & Lucassen, 1992). Due to this chromatic adaptation, the color of the circles of the stimulus field presented at exactly the same location as the circles of the premask *appear* to have a color which is slightly different from the color of the circle presented at a new location (i.e., the circle with onset). This might give a confound because the onsetting circle not only has onset but also a color which is slightly different from the rest. This effect does not occur with the color grey because this color consists of red, green and blue simulating the red, green and blue cones about equally.

Procedure

The task was identical to Experiment 1.

3.2 Results

Response times longer than 1 s were counted as errors, which led to a loss of well under 1% of the trials. Mean RT and error percentages are shown in Fig. 3.

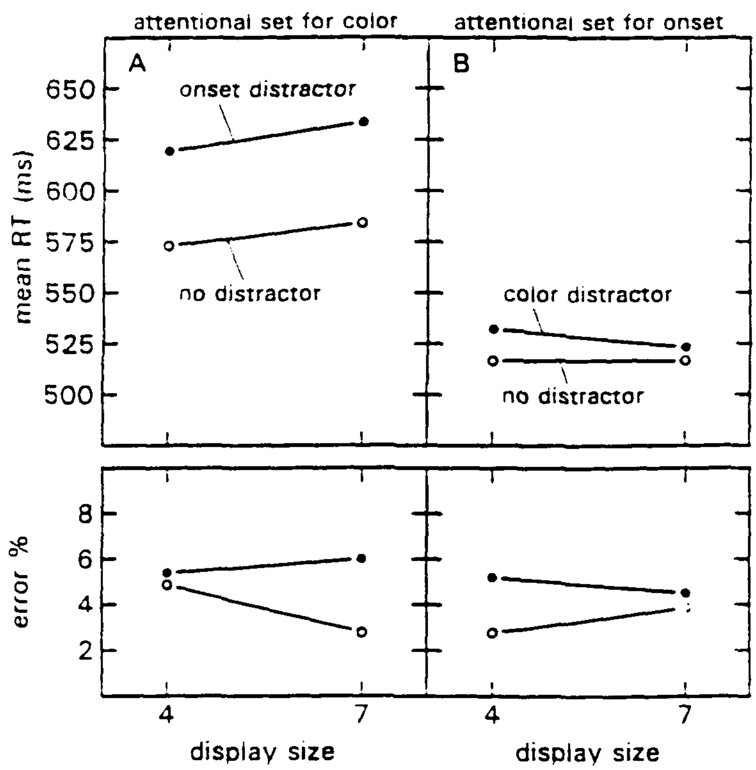

Fig. 3 Experiment 2: Mean reaction time and error percentages for search with or without a distractor for the color (Panel A) and onset (Panel B) conditions.

There was a main effect on RT for attentional set [$F(1,7) = 25.0$; $p < 0.01$], and distractor [$F(1,7) = 9.0$; $p < 0.05$]. Also, the interaction between these variables [$F(1,7) = 6.0$; $p < 0.05$] and the interaction between attentional set and display size were reliable [$F(1,7) = 11.5$; $p < 0.05$]. The mean slopes for the color condition, were 3.7 and 4.4 ms for the no-distractor and distractor condition. For the onset condition, these figures were respectively -0.04 and -3.0 ms. None of these slopes were significantly different from zero (all $t(7) < 1.09$), indicating parallel preattentive search across all items in the display. Planned comparisons showed, for the color condition, a significant difference between the mean RTs of the no-distractor condition and the distractor condition [$F(1,7) = 12.6$; $p < 0.01$], implying that search for the uniquely colored grey circle is slowed down by the abrupt onset circle. The same comparison for the onset condition shows that search for the abrupt onset circle is not affected by the presence of the uniquely colored grey circle [$F(1,7) < 1$]. Again, the distraction effect on RT did not depend on order of the presentation of the color and onset sessions (the interaction between order and distractor [$F(1,6) < 1$].

The arcsine transformed error data showed a reliable effect for the interaction attentional set, distractor and display size [$F(1,7) = 9.9$; $p < 0.05$]. This analysis indicates that the increase in RT caused by the onset distractor cannot be attributed to a speed-accuracy trade-off.

3.3 **Discussion**

The no-distractor conditions show that an onset is more salient than a grey circle between red circles (averaged over display size, no distractor condition: 602 ms for color and 522 ms for onset). In line with the hypothesis of Theeuwes (1991b, 1992), the present data indicate that selectivity depends on the relative saliency of the singletons present in the visual field: search for an onset was not hindered by the presence of a less salient color singleton. On the other hand, the salient onset interfered strongly with search for the color singleton. Again, the attentional set could not override the stimulus-driven capture of the more salient onset. It appears that the control of attention is independent of the observer's state of attentional readiness, a finding which challenges Folk et al.'s (in press) hypothesis.

4 GENERAL DISCUSSION

Two experiments were conducted to test the hypothesis that the control of attention is never purely stimulus driven as suggested by Folk et al. (in press). According to their hypothesis involuntary orienting of a attention to a stimulus event is contingent upon the attentional set of the observer. Thus, if an observer has an attentional set for a static discontinuity (a color singleton), other static singletons capture attention whereas dynamic discontinuity (abrupt onsets) can simply be ignored. Both experiments reported here show that this hypothesis does not hold: an attentional set for a static discontinuity cannot override the attentional capture of an abrupt onset.

The present findings together with those of Theeuwes (1991b, 1992) suggest a model of performance which assumes that the extent to which singletons capture attention is completely determined by the relative saliency of the singletons present in the visual field. Irrespective of the attentional set, spatial attention is automatically and involuntary captured by the most salient singleton. The shift of spatial attention to the location of the singleton, implies that the singleton is selected for further processing. If this singleton contains the target line segment, a response is given. If it does not contain the target line segment, attention is automatically switched to the next salient singleton. Because the saliency of the color and onset singleton were about equal in Experiment 1, attention was sometimes captured by the target and sometimes by the distractor, giving interferences for both the color and onset condition. Because the color difference was made smaller in Experiment 2, the onset singleton was always the most salient one and therefore always selected first. As a consequence, search for the onset singleton was not hindered by the presence of the color singleton, whereas the onset singleton always interfered with search for the color singleton.

According to the Theeuwes' model, in an unfocussed state of attention, the preattentive process simply calculates differences in features within dimensions, resulting in pattern of activations at different locations, followed by an automatic shift of spatial attention to the location with the highest difference signal. In this model, selection operates irrespective of the task demands, and the automatic shifts of attention can be considered the result of relatively inflexible, "hardwired" mechanism which are triggered by the presence of specific stimulus properties. In line with for example Sagi and Julesz (1985) and Ullman (1984) it is assumed that the parallel process can only perform a *local-mismatch* detection followed by a serial stage in which the most mismatching areas are selected for further analysis.

It is recognized that the operation of the "hardwired" capturing mechanism can be stopped voluntary by focussing of attention to a restricted area in the visual field (e.g., Yantis & Jonides, 1990; Theeuwes, 1991a). It is assumed that no preattentive processing occurs outside the area to which attention is directed. A consequence of this top-down strategy is that search is performed serially or partly serially. In the present study, subjects had to divide their attention over the whole visual field so that the task-relevant feature could capture attention; yet, as a consequence of this strategy the task-irrelevant feature could capture attention as well.

The data-driven selection model as described above is not in accordance with various recent models of visual search which do assume top-down effects on visual selection (e.g., Bundesen, 1990; Cave & Wolfe, 1990; Treisman & Sato, 1990). Generally, these models are based on data that show that attentional set (e.g., knowing that the target is a red circle) speeds up responding to this target (i.e., the red circle). In these typical visual search tasks, the item subjects are looking for during search, is also the item they have to respond to. As a consequence, attentional set does not only affect visual selection, but also affects processes (e.g., identification, response selection) that occur after the target has been selected. The present study does not contain this confound. Because subjects responded to the orientation of the target line segment located in the perceptually discrepant item, it is ensured that the RT data reflects effects operating at the early stage of perceptual processing rather than on processing operations occurring after the item has been selected (see also, Yantis, in press).

It might be argued that top-down effects did not show up in the present study because the target and distractor were so salient that attentional set could not override the attentional capture of these salient items. This argument might be valid for the interference found in Experiment 2; yet, in Experiment 1 color and onset singletons were about equally salient. If top-down effect would exist, they should have showed up under these circumstances.

REFERENCES

Broadbent, D.E. (1958). Perception and communication. London: Pergamon.

Broadbent, D.E. (1982). Task combination and the selective intake of information. Acta Psychologica 50, 253-290.

Bundesen, C. (1990). A theory of visual attention. Psychological Review 97, 523-547.

Cave, K.R., & Wolfe, J.M. (1990). Modeling the role of parallel processing in visual search. Cognitive Psychology 22, 225-271.

Folk, C.L., Remington, R., & Johnston, J.C. (in press). Involuntary covert orienting is contingent on attentional control settings. Journal of Experimental Psychology: Human Perception and Performance.

Jonides, J. (1981). Voluntary v. automatic control over the mind's eye's movement. In J.B. Long & A.D. Baddeley (Eds), Attention and Performance IX (pp. 187-203). Hillsdale, NJ: Erlbaum.

Jonides, J., & Yantis, S. (1988). Uniqueness of abrupt visual onset in capturing attention. Perception & Psychophysics 43, 346-354.

Jonides, J. & Mack, R. (1984). On the cost and benefit of cost and benefit. Psychological Bulletin 96, 29-44.

Miller, J. (1989). The control of attention by abrupt visual onsets and offsets. Perception & Psychophysics 45, 567-571.

Müller, H.J. & Rabbitt, P. M. A. (1989). Reflexive and voluntary orienting of attention: Time course of activation and resistance to interruption. Journal of Experimental Psychology: Human Perception and Performance 15, 315-330.

Neisser, U. (1967). Cognitive Psychology. New York: Appleton-Century-Crofts.

Neumann, O. (1984). Automatic Processing: A review of recent findings and a plea for an old theory. In W. Prinz & A.F. Sanders (Eds), Cognition and motor processes (pp. 55-290). Berlin: Springer-Verlag.

Pashler, H. (1988). Cross-dimensional interaction and texture segregation. Perception & Psychophysics 43, 307-318.

Posner, M. (1980). Orienting of attention. Quarterly Journal of Experimental Psychology 32, 3-25.

Sagi, D., & Julesz, B. (1985). "Where" and "what" in vision. Science 228, 1217-1219.

Theeuwes, J. (1990). Perceptual selectivity is task-dependent: evidence from selective search. Acta Psychologica 74, 81-99.

Theeuwes, J. (1991a). Exogenous and endogenous control of attention: The effect of visual onsets and offsets. Perception & Psychophysics 49, 83-90.

Theeuwes, J. (1991b). Cross-dimensional perceptual selectivity. Perception & Psychophysics 50, 184-193.

Theeuwes, J. (1992). Perceptual selectivity for color and form. Perception & Psychophysics 51, 599-606.

Theeuwes, J. & Lucassen, M.P. (1992). A spurious pop-out in visual search. Manuscript submitted for publication.

Treisman, A.M. & Gelade, G. (1980). A feature integration theory of attention. Cognitive Psychology 12, 97-136.

Treisman, A.M. & Gormican, S. (1988). Feature search in early vision: Evidence from search asymmetries. Psychological Review 95, 15-48.

Treisman, A.M., & Sato, S. (1990). Conjunction search revisited. Journal of Experimental Psychology: Human Perception and Performance 16, 459-478.

Ullman, S. (1984). Visual routines. Cognition 18, 97-159.

Yantis, S. & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from selective search. Journal of Experimental Psychology: Human Perception and Performance 10, 601-621.

Yantis, S. & Jonides, J. (1990). Abrupt visual onsets and selective attention: Voluntary versus automatic allocation. Journal of Experimental Psychology: Human Perception and Performance 16, 121-134.

Yantis, S. (in press). Stimulus driven attentional capture. Journal of Experimental Psychology: Human Perception and Performance.

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15. ABSTRACT (MAXIMUM 200 WORDS, 1044 BYTE)

Recent evidence suggests that the occurrence of attentional capture is contingent on the attentional control setting induced by the task demands (Folk, Remington & Johnston, in press). Because the experiments on which these conclusions are based can be criticized for several reasons, the contingent capture hypothesis was tested by means of two visual search tasks in which subjects searched multielement displays in which a color singleton and onset singleton were simultaneously present. When subjects had to search for a color singleton, on some trials another location contained an irrelevant onset. In addition, when subjects had to search for a onset singleton, on some trials another location contained an irrelevant color singleton. Both experiments show that the contingent capture hypothesis does not hold: irrespective of attentional set, attention was captured by the most salient singleton. The results of these experiments, together with previous findings, suggest a stimulus-driven model of performance in which selection is completely determined by the properties of the objects present in the visual field.

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